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PREDICTIVE MODELING FOR THE PROPOSED TENNESSEE COLONY LAKE BASE--ETC(U)
APR 78 J A NUSSER, A H PLUMMER DACW63-77-C-0003

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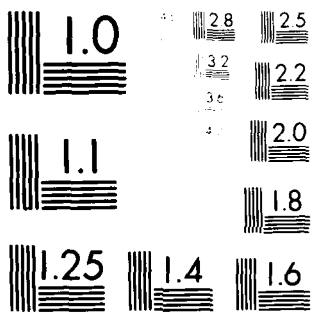
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The purposes of this study are to provide an assessment of the effects of upstream developmental activities upon Lake Livingston phytoplankton biomass, and to provide a predictive assessment of potential water quality conditions, with particular emphasis on eutrophication, for the proposed Tennessee Colony Lake. The Summary presents a listing of basic study conclusions, an overview of the study goals, a description of the eutrophication models, a review of the Lake Livingston model calibration and validation, a discussion of chlorophyll

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20. 'a' as a water quality parameter, a description of the flows, solids, and nutrient input patterns to the models, a summary of chlorophyll 'a' projections for Tennessee Colony Lake and Lake Livingston, a description of potential impacts of Tennessee Colony Lake on the productivity of Lake Livingston, a discussion of the remaining uncertainties regarding the lake eutrophication models, and a summary of several auxiliary studies concerned with the effects of barge traffic and the effects of changing land use patterns.

EXECUTIVE SUMMARY

PREDICTIVE MODELING FOR THE PROPOSED TENNESSEE COLONY LAKE BASED UPON EUTROPHICATION ANALYSIS OF LAKE LIVINGSTON, TEXAS (PHASE I)

APRIL 1978

Prepared under contract DACW63-77-0003
for the Fort Worth District, U.S. Army Corps of Engineers
by

Arlington, Texas
Westwood, New Jersey

Hydroscience

April 17, 1978

Mr. Robert E. Lyman
Department of the Army
Fort Worth District, Corps of Engineers
P.O. Box 17300
Fort Worth, Texas 76102

Dear Mr. Lyman:

We are pleased to submit herewith the Executive Summary of our report, "Predictive Modeling for the Proposed Tennessee Colony Lake Based Upon Eutrophication Analysis of Lake Livingston, Texas (Phase I)," prepared under contract DACW63-77-C-003 with the U.S. Army Corps of Engineers, Fort Worth, Texas.

The Summary presents the following topics: (a) a listing of the basic conclusions for the study, (b) an overview of the study goals, (c) a description of the eutrophication models, (d) a discussion of chlorophyll 'a' as a water quality parameter, (e) a description of the flows, solids, and nutrient input patterns to the models, (f) a review of the Lake Livingston model calibration and validation, (g) a summary of chlorophyll 'a' projections for Tennessee Colony Lake and Lake Livingston, (h) a description of the potential impacts of Tennessee Colony Lake on the productivity of Lake Livingston, (i) a discussion of the remaining uncertainties regarding the lake eutrophication models, and (j) a summary of several auxiliary studies concerned with the effects of barge traffic and the effects of changing land use patterns.

May we express our appreciation for your cooperation and helpful assistance, as well as that of your staff. The members of the Hydroscience, Inc., staff who have contributed directly to these investigations include Mr. John Novak, Dr. Michael A. Collins, Mr. Joseph Larkin, Dr. Dominic Di Toro, Mr. John L. Mancini, Mr. Walter Chiang, Ms. Claudia Zahorcak, and Dr. Jonathan Young.

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EXECUTIVE SUMMARY

Conclusions

A number of conclusions can be drawn from this study and from previous Hydroscience studies of the Lake Livingston reservoir.

1. Appreciable algae growth will occur in the proposed Tennessee Colony Lake. The magnitude of the growth as indicated by projections of chlorophyll 'a' levels made by the eutrophication model will be on the order of 5.0 to greater than 150 μg/l. These levels are currently being experienced in other Texas reservoirs as reflected by data shown in the following table.

Impoundment	Range of Chlorophyll 'a' (μg/l)
Lake Livingston	4 - 80
Lake Tawakoni	1.4 - 61.2
Trinidad Lake	2.3 - 34.9
Wright Patman Reservoir	1.5 - 57.0
Somerville Lake	5.9 - 53.7
Lake Houston	0.5 - 111.5
Lake O'The Pines	2.6 - 44.2
Palestine Reservoir	1.7 - 34.5
Sam Rayburn Reservoir	1.9 - 17.3
Lake Ray Hubbard	5 - 163

(Source: U.S. Environmental Protection Agency, National Eutrophication Survey)

2. The eutrophication model constructed for the proposed Tennessee Colony Lake is at a level of confidence adequate for making an initial assessment of anticipated algae growth conditions. This level of confidence is based on a relatively good validation of the model kinetics as applied to Lake Livingston. This validation was accomplished without the benefit of the inclusion of 1) the effect of nitrogen fixing algal forms in Lake Livingston, 2) hypolimnetic denitrification, and 3) nutrient uptake and release by macrophytes. The current level of development of the eutrophication model allows projections of algae conditions throughout an entire year based on defined initial conditions. The model does not properly predict the year-to-year carryover of water quality conditions.

    However, the validation made with data collected during 1976 in Lake Livingston supports a conclusion that the eutrophication model developed for the proposed Tennessee Colony Lake is adequate for this initial assessment of anticipated algae conditions in Tennessee Colony.

3. Dissolved oxygen in the surface layers of the proposed Tennessee Colony Lake will probably be depressed to levels less than a stream standard level of 5 mg/l. This is the standard applied to most water bodies in the State of Texas. Dissolved oxygen in the bottom waters of the proposed lake will probably be depleted during periods of thermal stratification.

The projection of the occurrence of these depressions in the Tennessee Colony Lake is based upon 1) surface dissolved oxygen measurements made in Lake Livingston which are less than the 4-5 mg/l range, 2) the measured seasonal depletion of dissolved oxygen in the hypolimnion of Lake Livingston, 3) the location of the proposed Tennessee Colony Lake at closer proximity to upstream oxygen demanding loads introduced to the Trinity River, and 4) the projected growth of algae in the proposed lake which can also be a dissolved oxygen sink.

4. Portions of Lake Livingston are now light limited, rather than nutrient limited, during portions of the year. Substantial reductions in the suspended solids concentrations being introduced to Lake Livingston are projected to shift the timing of maximum algae growth. Model results indicate that these reductions would also increase the annual average productivity, particularly in the upstream portion of the reservoir during higher flow years.

5. Analysis of available data and model computations show chlorophyll 'a' is an appropriate indicator of both algal numbers and of primary production in Lake Livingston. Thus projections based upon chlorophyll 'a' concentrations are meaningful indicators of the trophic state of the Lake Livingston reservoir and by extension, of the proposed Tennessee Colony Lake.

6. Nutrient and suspended sediment loadings in the Trinity River at Rosser, Crockett, and the inflow

to Lake Livingston are flow related. Nutrient concentrations vary as an inverse function of flow; suspended sediment concentrations vary as a direct function of flow. Annual mass loadings of both nutrients and suspended sediment are flow dependent; total mass is significantly higher in a high flow year than a low flow year.

7. Not enough information is available to conclude whether macrophytic plants will become established within the new Tennessee Colony Lake. However, the similarity in flow, geometry and location to the Lake Livingston reservoir suggest the probability of such infestation.

8. The impact of potential barge traffic upon suspended sediment generation is small. Barge traffic effects are judged to be local in nature and not a major factor affecting algal productivity.

9. Additional studies could be performed which would greatly increase the understanding of eutrophication conditions in Lake Livingston, the Trinity River, and the proposed Tennessee Colony Lake. These studies are of both a practical and a scientific nature. No attempt is made to differentiate among the studies as to either timing or level of importance. That mission is left to the funding agencies.

   a. The observed dissolved oxygen problem in the Lake Livingston reservoir and the potential problem in the proposed Tennessee Colony Lake should be examined in light of the damage possible to fish and other aquatic forms and with regard to the occasional contravention of stream standards. It is recommended that the extent of the phytoplankton effects on dissolved oxygen in Lake Livingston be addressed and quantified within the present modeling framework.

b. If increased confidence in numerical projections is required, the nitrogen sources and sinks not presently included in the model should be addressed and quantified. This refinement of model kinetics should also address the problem of year to year nutrient carry over in the reservoir. Such refinements may be necessary to fully explain dissolved oxygen relationships in the reservoirs.

c. In order to directly address the impact of Tennessee Colony Lake on the Lake Livingston reservoir it would be necessary to construct a model which includes the intervening Trinity River so that nutrients and suspended sediments can be properly routed and settled as a function of river flow. This would be a complex technical task involving issues at the forefront of present knowledge.

d. A research program, perhaps by an educational institution, should be funded to address the problem of macrophytes. This problem is not peculiar to the Lake Livingston reservoir, but exists in numerous other areas. Lack of information on controlling factors prohibit an examination of the effects of control alternatives on these macrophytes for the present study. It is therefore recommended that a series of experiments be conducted to determine nutrient pathways and kinetics for these macrophytes so as to produce an understanding for possible control measures.

Project Overview

The purposes of this study are to provide an assessment of the effects of upstream developmental activities upon Lake Livingston phytoplankton biomass, and to provide a predictive assessment of potential water quality conditions, with particular emphasis on eutrophication, for the proposed Tennessee Colony Lake.

These objectives have been accomplished by the modification of an existing eutrophication model of the Lake Livingston reservoir to predict light extinction from total suspended solids, the recalibration and validation of this model for two years of Lake Livingston water quality data, and the use of the same model kinetics for the development of a eutrophication model for the Tennessee Colony Lake. Each model was then run in a series of projections to provide the bases for the required assessment.

Other phases of the study have been completed which relate to barge traffic generation of suspended sediments and to the impact of basin development and land use upon suspended sediment loadings. These portions of the study were necessary for the quantitative assessment of the impacts associated with those activities.

Eutrophication Model Description

An existing, phytoplankton-based, eutrophication model of the Lake Livingston reservoir has been refined for use in the present study. The model framework incorporates the parameters shown in Figure P1, an idealization of algal interactions with light, temperature, and nutrients. The bases of the model are a series of differential equations in time and space describing the rate of change of the substance of interest with respect to itself and with respect to the other variables interacting with it. The principle incorporated in these equations is conservation of mass. That is, all mass entering and leaving the model must be accounted for in a mass balance. By numerical integration on a digital computer, the model calculates the distribution of each variable at discrete times in the simulation. The variables incorporated in the model and their interactions are shown schematically in Figure P2. The recycle implicit in the system is clear. Inorganic forms of the nutrients nitrogen and phosphorus are assimilated by the phytoplankton for the synthesis of new algal cells. The phytoplankton, by the mechanisms of death, endogenous respiration, and predation, are themselves cycled into non-living organic nutrients, which are then transformed by chemical and biological mechanisms into organic nutrients.

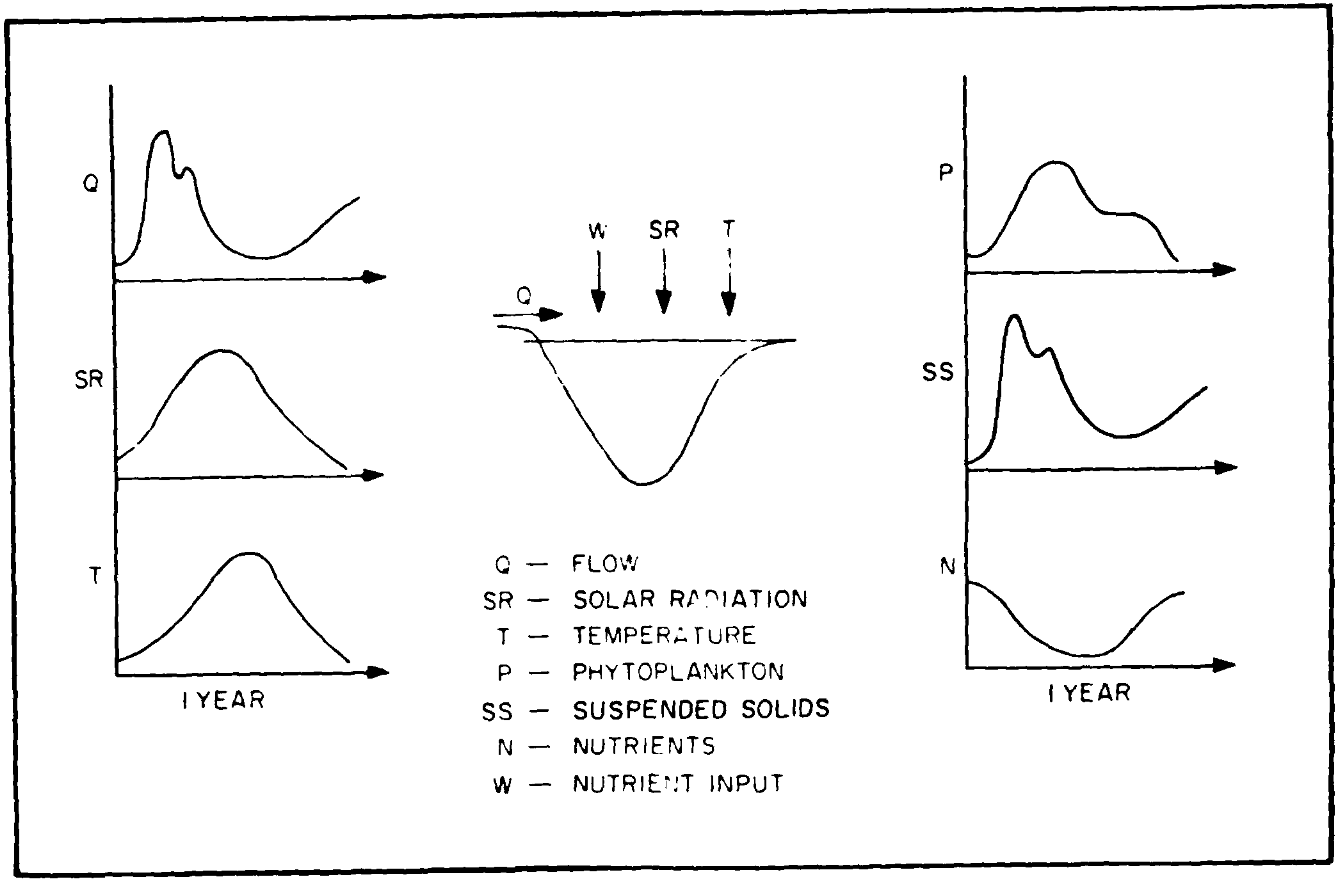


FIGURE P I

SEASONAL VARIATION OF FLOW, SOLAR RADIATION, TEMPERATURE PHYTOPLANKTON, SUSPENDED SOLIDS AND NUTRIENTS

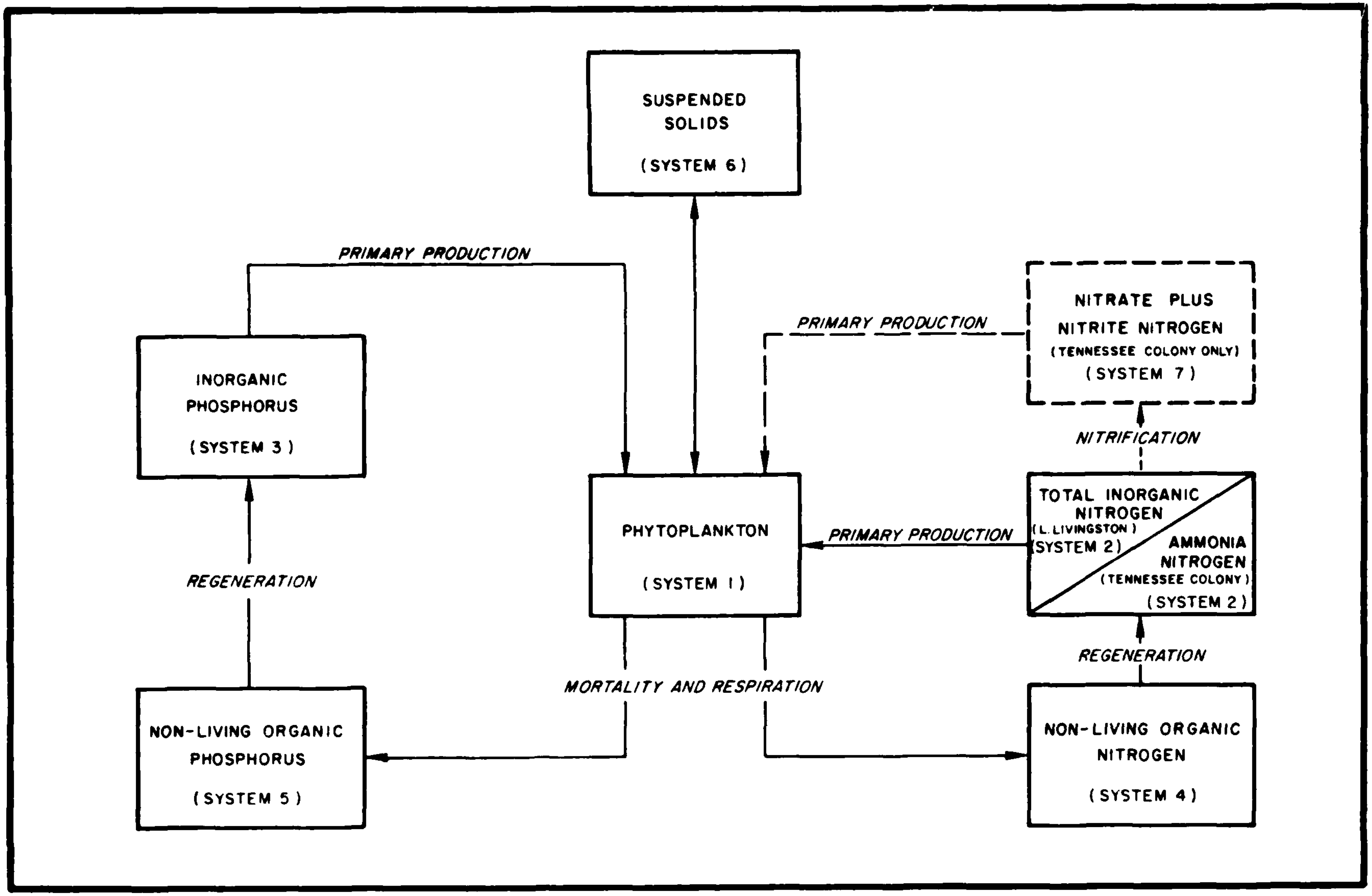


FIGURE P 2
MODEL KINETICS

Chlorophyll 'a' As a Water Quality Indicator

Chlorophyll 'a', as a measure of phytoplankton biomass, is the model variable by which comparisons of lake trophic state are made. Chlorophyll 'a' is a direct measurement of the quantity of photosynthetic plant pigments present. It can be related directly to oxygen production. Additionally, as the agent which generates energy for the cell, it should provide a better correlation to growth rate and nutrient utilization than other measures of population size. It is a measurement used by governmental agencies and is widely recognized as being appropriate and useful in providing a practical basis for estimates of relative numbers of photosynthetic organisms in nature waters.

Some disagreement exists as to the efficacy of chlorophyll 'a' as such an indicator variable. The arguments center about the variability of chlorophyll 'a' per unit cell volume, or per unit of plant carbon as a function of species and environmental factors. In the present case chlorophyll 'a' is a valid parameter indicative of both algal numbers and of photosynthetic ability. Figure P3 presents a comparison of chlorophyll 'a' data and total algal counts as collected by the Texas Water Quality Board (now The Texas Department of Water Resources) in Lake Livingston on four occasions in 1975 and early 1976. Four seasons of data are represented. Breakdown of total counts by survey reveals significant species shifts from season to season (the population is predominantly diatoms in winter, greens in spring, blue-greens in summer and fall). The overall correspondence indicated suggests that, even given the seasonal variability and species shifts, chlorophyll 'a' is a good

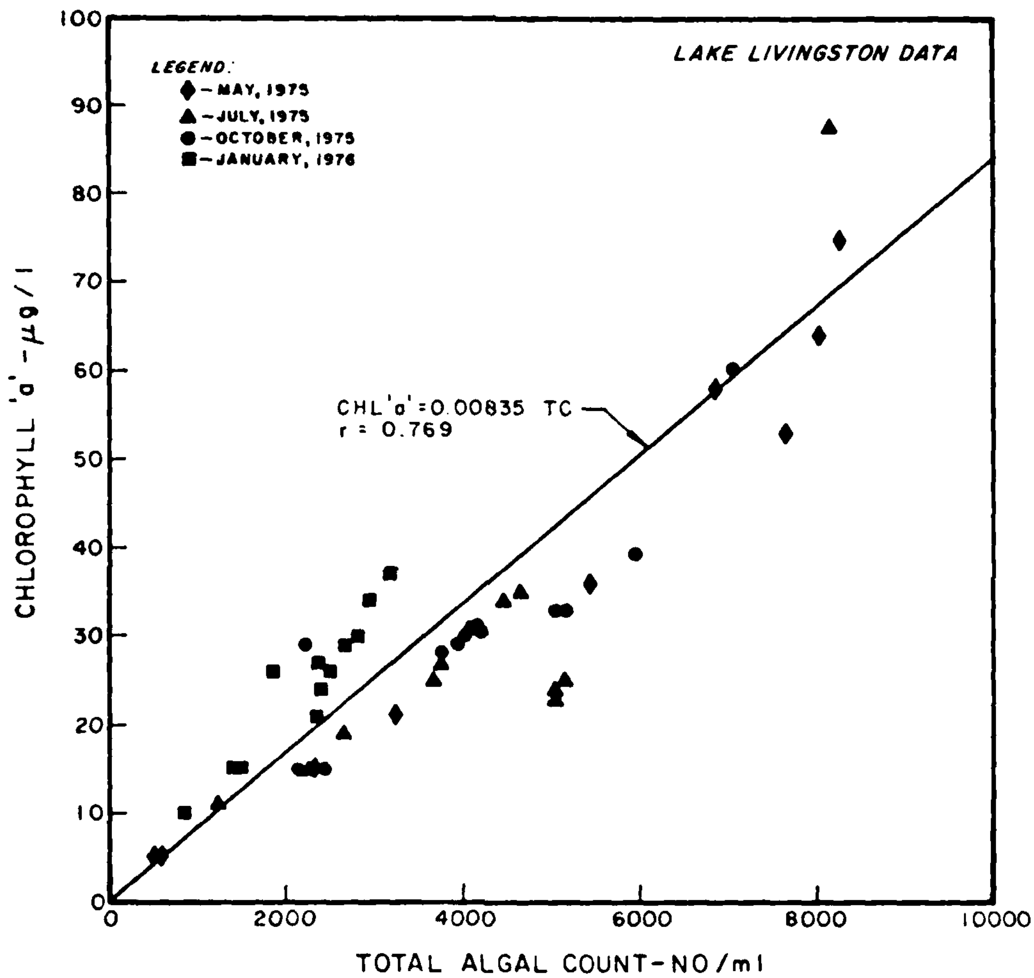


FIGURE P 3

TOTAL ALGAL COUNTS versus CHLOROPHYLL 'a' indicator of algal counts. A later figure, presented as part of the model validation, will demonstrate the relationship of chlorophyll 'a' to primary productivity measurements.

Unlike an assessment of the significance of several parameters, the interpretation of the impact of algal levels is somewhat subjective. For example, water quality parameters such as dissolved oxygen have certain, almost universal standards of acceptance. Dissolved oxygen concentrations of 1.0 mg/l in any natural water body would almost certainly be interpreted as being unacceptable. Chlorophyll 'a' is a different type of parameter. There is no absolute measure of acceptability independent of considerations of water use objectives. For example, it can be demonstrated that increasing algal levels may interfere with water use. Figure P4 presents data, collected at a water treatment plant, which show a high degree of correlation between algal counts and odor. High algal concentrations may, therefore, interfere with use of a reservoir as a water supply. However, very low algal levels may not allow for the use of a water body as a fishery. Further, levels that might be desirable in an estuary may not be acceptable in a lake.

Several agencies in different regions of the United States use chlorophyll 'a' as an indicator when setting goals or objectives for water use. A comparison of such goals is shown graphically in Figure P5. It is clear from the figure that the objectives set for the San Joaquin Delta in California, a rich, productive fishery, are much different than those proposed for either Lake Erie or Lake Superior. The objectives for the lakes themselves are

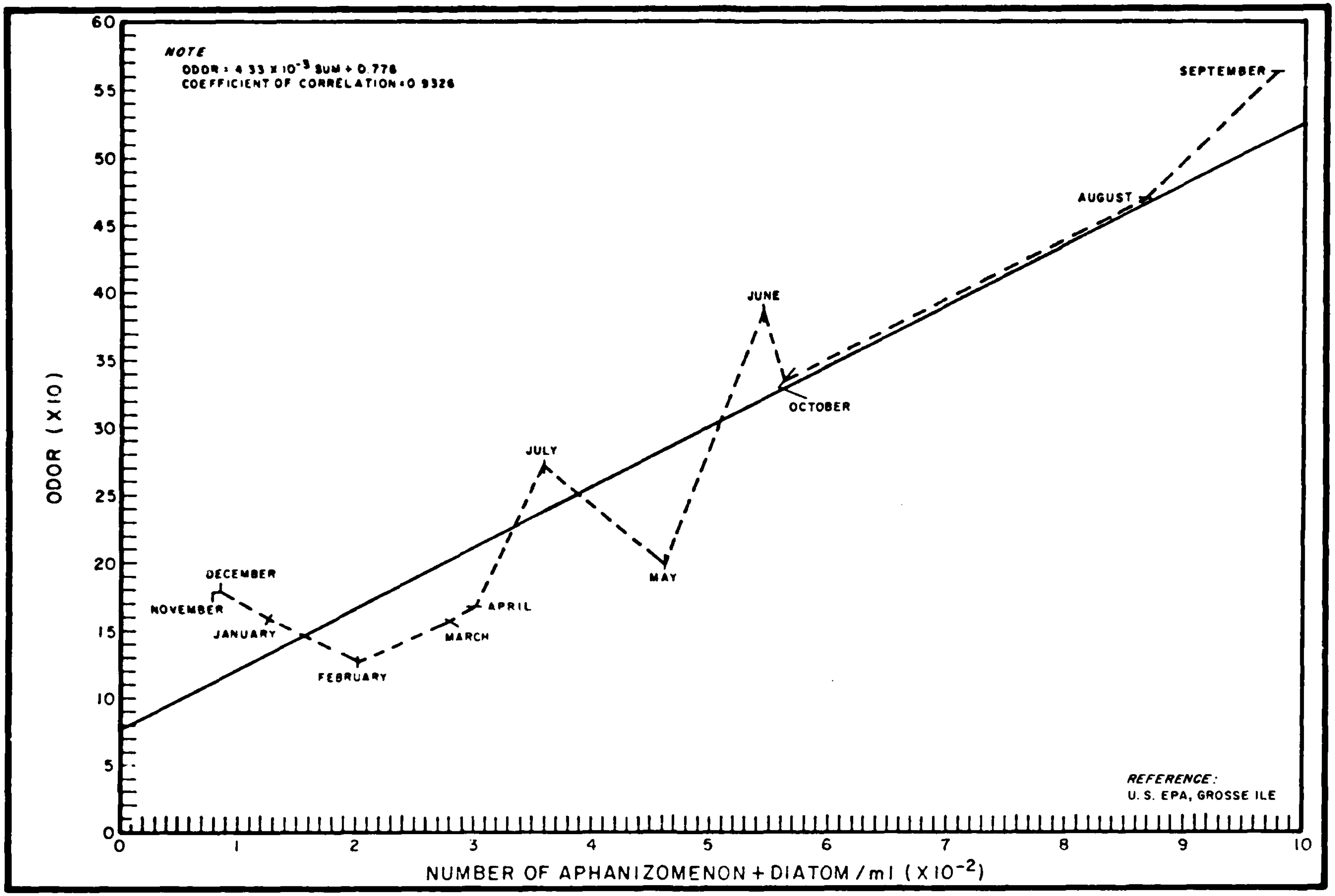


FIGURE P 4

ODOR VERSUS PHYTOPLANKTON NUMBERS

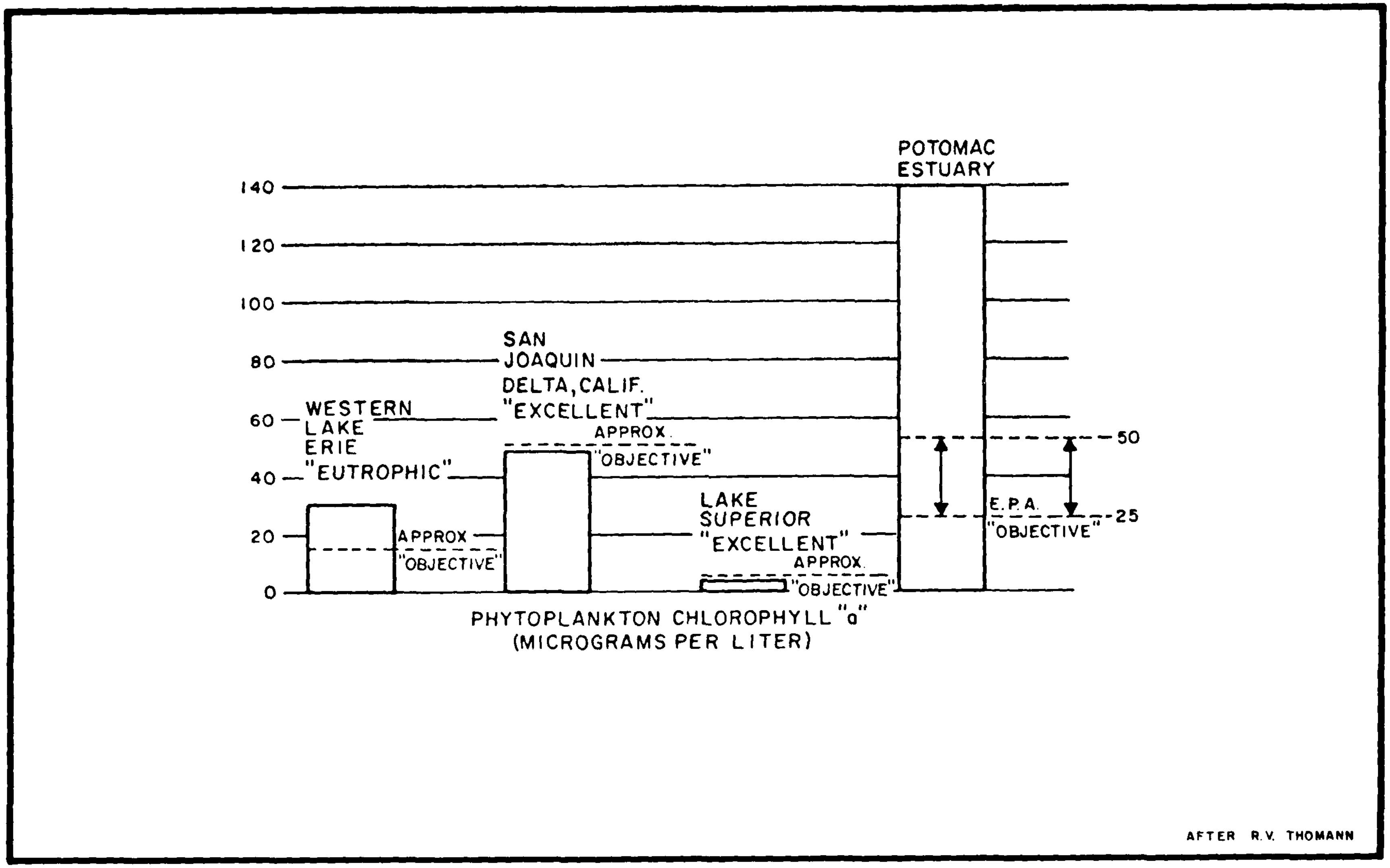


FIGURE P 5

COMPARISON OF REGIONAL CHLOROPHYLL 'a' OBJECTIVES very different, reflecting the very different water uses intended for each water body.

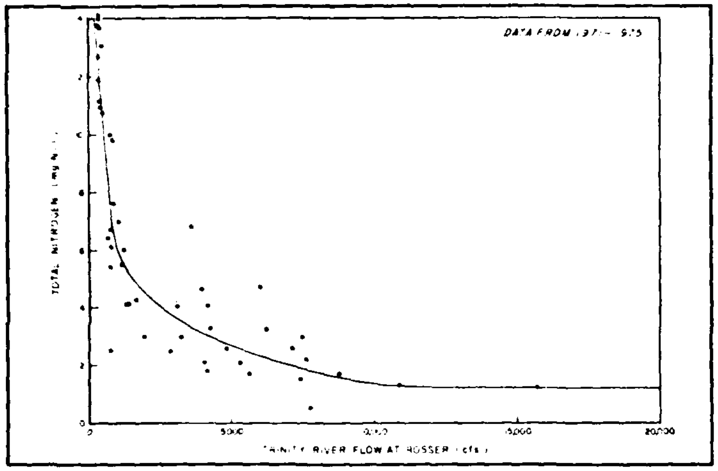
Trinity River Hydrology

An examination of available Trinity River monthly flow records at Tennessee Colony (47 years) and at Crockett (13 years) indicates two general recurring annual hydrologic patterns. One may be characterized as having high flows in the month of May with lower flows during the earlier and latter portions of the year; the other as having low flows for the entire year. In either case, summer flows are generally below 1000 cfs.

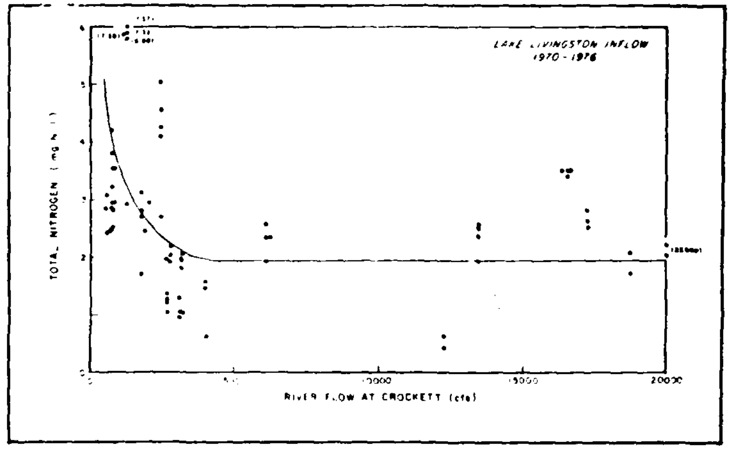
These two patterns are used in all projection runs to bracket the range of flow related effects to be expected.

Flow Related Loadings

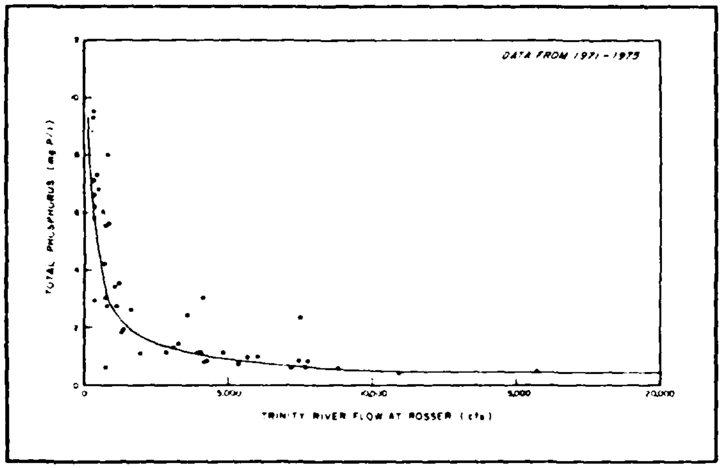
Flow related nutrients and total suspended solids concentration rating curves have been developed for several locations on the Trinity River. The intention is to provide a mechanism for assigning necessary model boundary conditions for projection purposes. Figures P6 and P7 present examples of nutrients and total suspended solids rating curves respectively. While some scatter is evident in the data, the general trends are clear. Nutrient concentrations decrease in a dilutional fashion to some background value as flow increases; suspended solids concentrations increase with increasing flow as a result of increased stream turbulence.



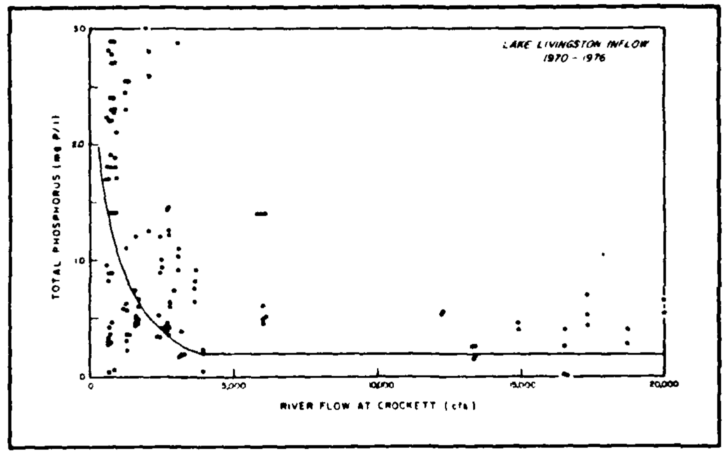
TOTAL NITROGEN VERSUS RIVER FLOW
AT ROSSER, TEXAS



TOTAL NITROGEN AT RIVERSIDE VERSUS RIVER FLOW
AT CROCKETT, TEXAS

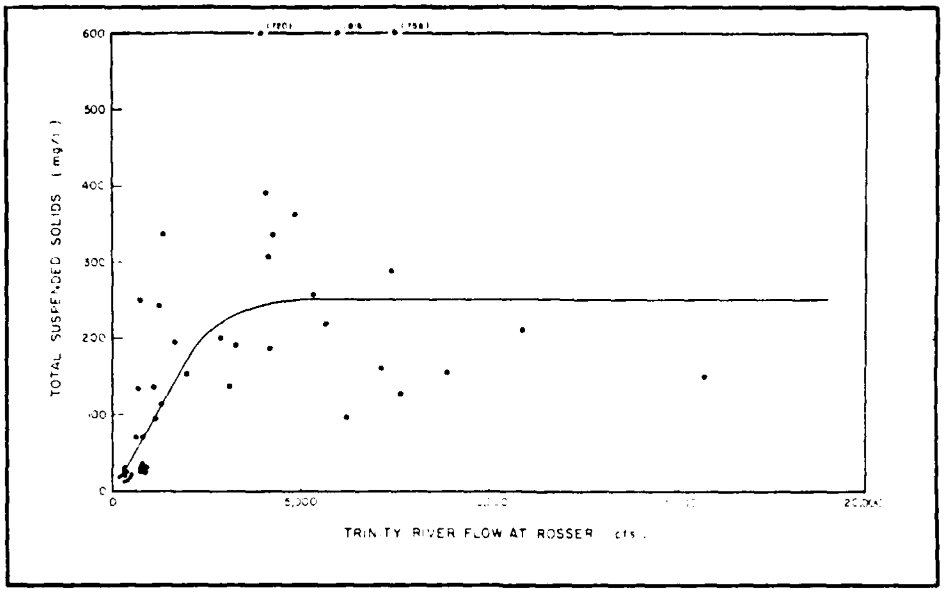


TOTAL PHOSPHORUS VERSUS RIVER FLOW
AT ROSSER, TEXAS

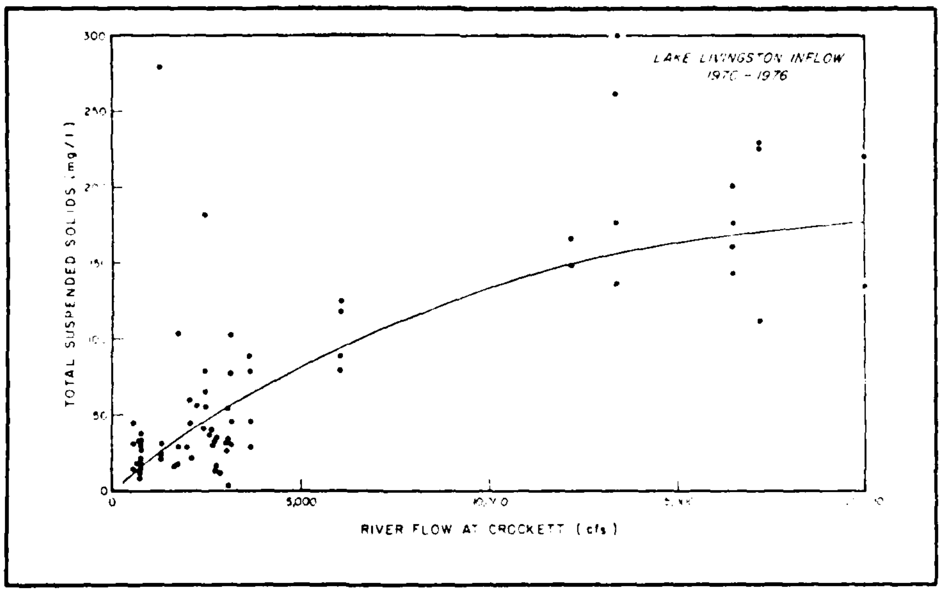


TOTAL PHOSPHORUS AT RIVERSIDE VERSUS RIVER FLOW
AT CROCKETT, TEXAS

FIGURE P 6
EXAMPLES OF NUTRIENT RATING CURVES AT ROSSER AND LAKE LIVINGSTON



TOTAL SUSPENDED SOLIDS VERSUS RIVER FLOW
AT ROSSER, TEXAS



TOTAL SUSPENDED SOLIDS AT RIVERSIDE VERSUS RIVER FLOW
AT CROCKETT, TEXAS

FIGURE P 7
ROSSER AND LAKE LIVINGSTON
TOTAL SUSPENDED SOLIDS RATING CURVES

Use of rating curves rather than discrete data to assign reservoir influent concentrations attempts to remove a form of sampling bias from the modeling work. For many reasons, only a finite number of data points are available for using in defining model loadings. The concentrations measured are the result of many factors such as load, flow, temperature, and sunlight. Each of these factors is subject to variations which can introduce bias into any single measurement. The intent in the use of the rating curves is to remove this bias. The result is an increased confidence in the calibrated and validated model due to the reliance on the rating curves with their implicit inclusion of flow r lated mechanisms. This increased confidence is also associated with the Tennessee Colony model projections.

Model Calibration and Validation

A principle component in the development and use of any model, particularly a eutrophication model, is a detailed validation procedure. The interactions which affect natural phytoplankton populations are of a complex and interrelated nature; therefore, i: is important that all the variables involved in the analysis be compared to observed data so as to assure that the proper structure and parameter values are being utilized in the model. The more complex the model the less likely it is to obtain a precise fit of all data.

A phytoplankton model is considered well calibrated if it can correctly reproduce overall chlorophyll 'a' concentration levels and tract identifiable trends in observed phytoplankton data while simultaneously providing a reasonable representation of nutrient interactions and the total nutrient balance in the water body.

The Lake Livingston eutrophication model has been calibrated using all available 1975 water quality data, as collected by several agencies, and validated using all available 1976 data from the same sources. The same model coefficients and constants are used for both years. The only differences from year to year occur in the flow patterns, and subsequently in the model boundary conditons via the rating curves. Each of the model variables is calculated simultaneously, providing added confidence in the model's ability to reproduce observed data. Additionally, calculation of primary production, total nitrogen, and total phosphorus provides checks on model kinetics.

Figure P8 presents the segmentation for the Lake Livingston model. Figure P9 presents the model calibration (1975) and model validation (1976) for two typical model segments, one in the upper reservoir in the vicinity of the "jungle" (segment 9), the other in the lower reservoir just above the dam (segment 1). The "jungle" is a recognized area of increased algal activity in the midsection of the lake. The comparison is between observed data and model calculations for total phosphorus and total nitrogen. The ability to reproduce the total nitrogen and total phosphorus profiles indicates whether model mechanisms are correctly accounting for the net sources and sinks of these total nutrients. Therefore, these calibration plots provide a check on the transport regime of the model as well as the loading to the reservoir. In general, the comparisons are good, although there is a discrepancy in the total nitrogen trend in the upper reservoir in the latter part of 1975. Observed

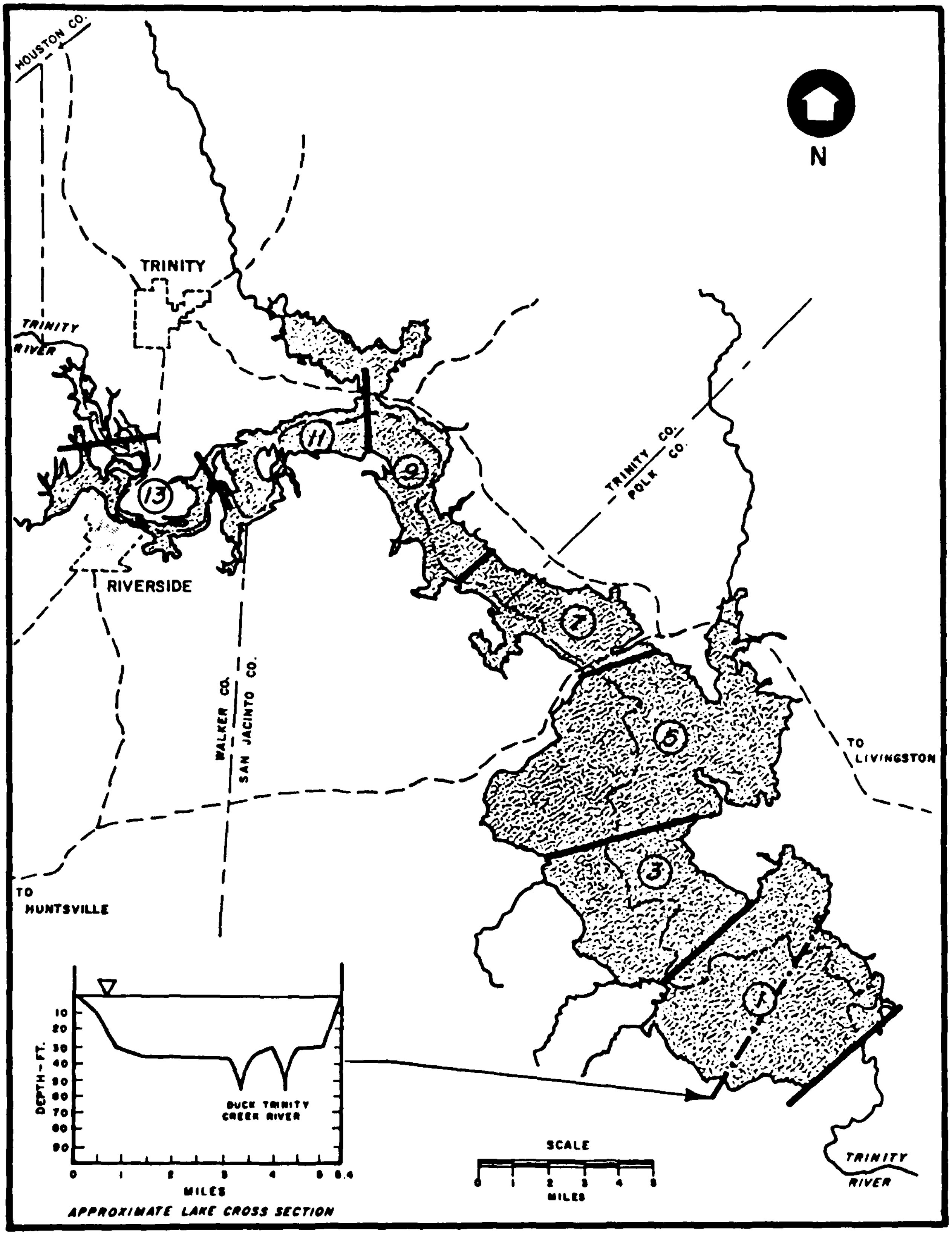


FIGURE P8

MAP OF LAKE LIVINGSTON, TEXAS SHOWING SEGMENTS USED IN THE MODEL

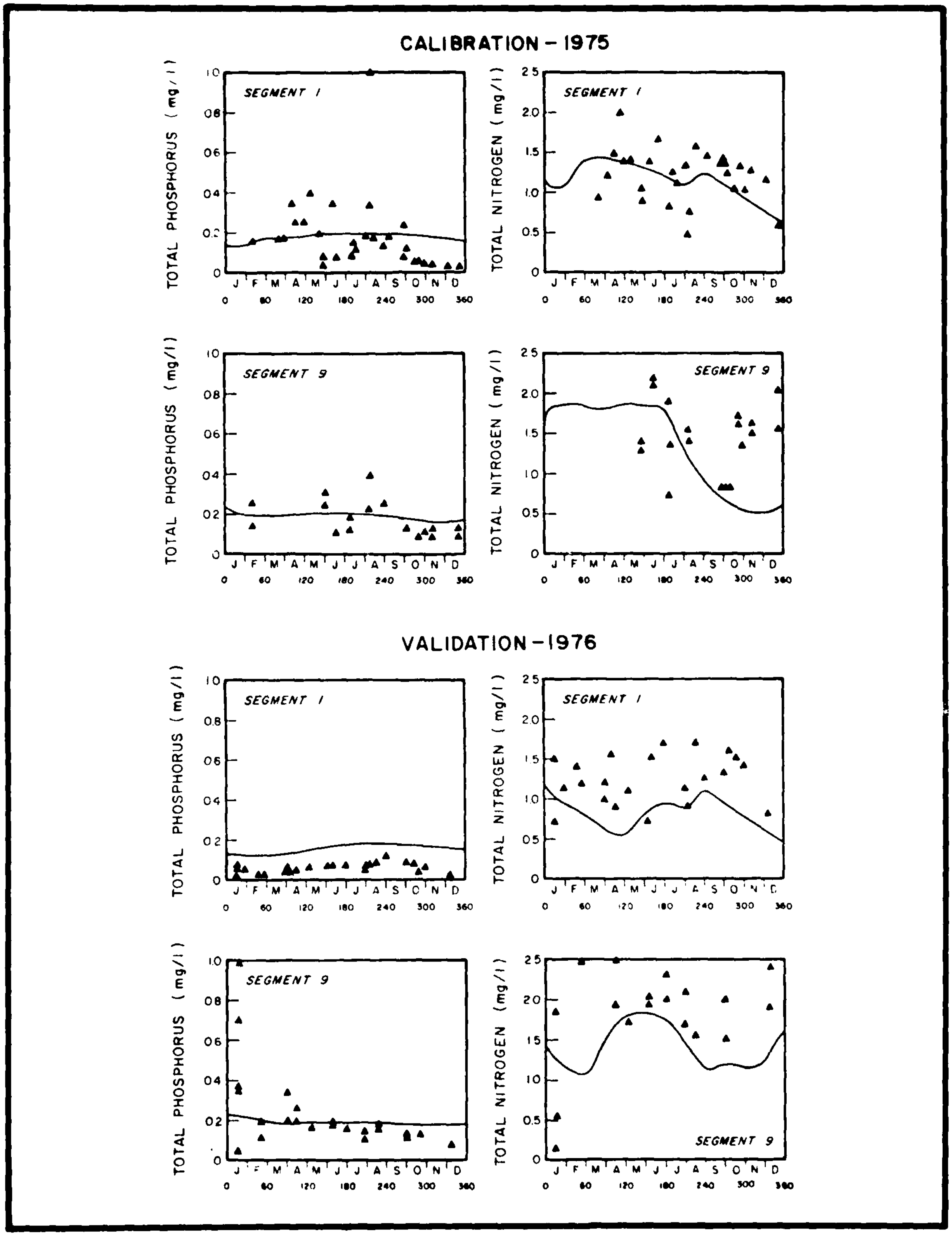


FIGURE P 9

MODEL CALIBRATION AND VALIDATION FOR TOTAL NUTRIENTS

nitrogen concentrations during that period were substantially higher than those idealized by the rating curves. The model also overestimates total phosphorus in the lower reservoir in 1976.

It is possible to improve the overall comparison between calculated and observed concentrations by use of observed data rather than concentrations derived from the rating curves for the specification of model boundary conditions. However, this would introduce problems in the specification of model boundary conditions for projection purposes in both Lake Livingston reservoir and Tennessee Colony Lake since no observed data exist for these conditions. Since the rating curves do account for the major trends in the concentration data and thereby permit the assignment of realistic concentration values for projection conditions, the rating curves were used for model calibration and validation, as well as for projections.

Figure P10 presents the orthophosphorus and organic nitrogen calibration and validation. The comparisons are considered good, again with the exceptions of the upper reservoir nitrogen in the latter part of 1975 and lower reservoir orthophosphorus in 1976. The trends in orthophosphorus concentrations are, however, correctly reproduced by the model. Seasonal depletions of orthophosphorus are neither observed nor calculated.

Figure P11 presents the model calibration and validation for total suspended solids and light extinction coefficient for the same two model segments. The comparisons for total suspended solids are considered good, both

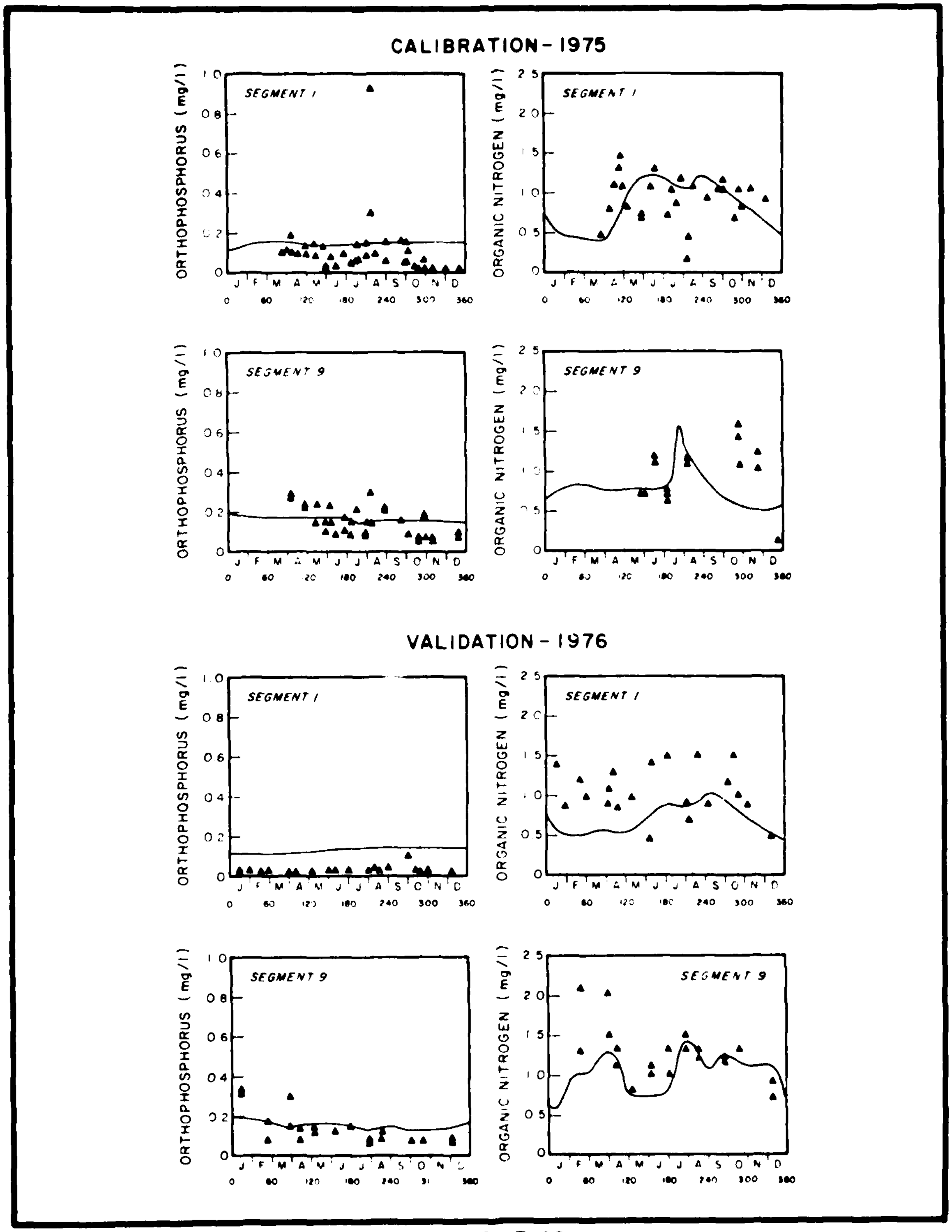


FIGURE P 10

MODEL CALIBRATION AND VALIDATION FOR ORTHOPHOSPHORUS AND ORGANIC NITROGEN

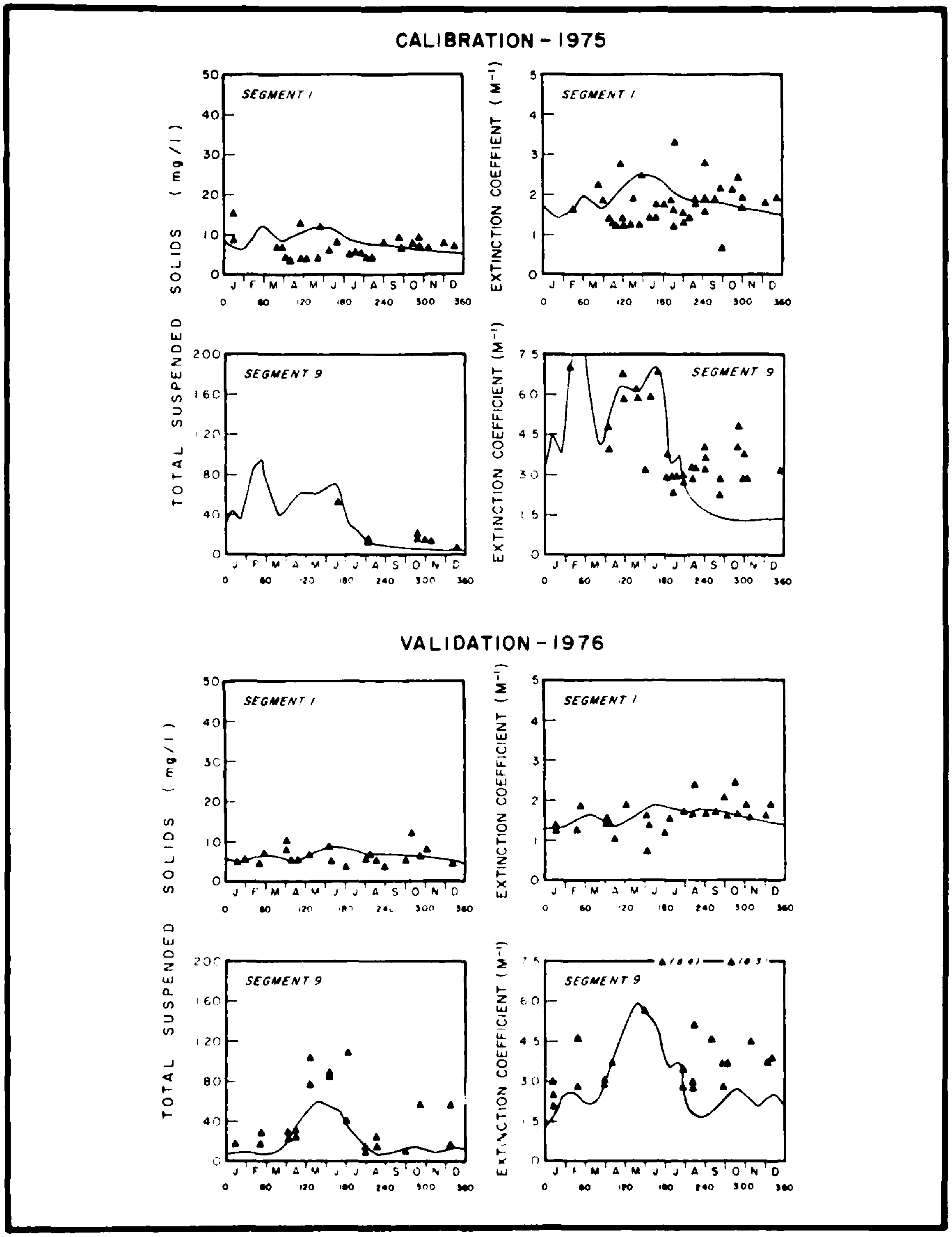


FIGURE P II

MODEL CALIBRATION AND VALIDATION FOR TOTAL SUSPENDED SOLIDS AND LIGHT EXTINCTION

in the lower and in the upper reservoir. The subsequent calculation of the light extinction coefficient from total suspended solids and chlorophyll is considered quite good, particularly in the upper reservoir where the magnitude of the extinction coefficient changes substantially over the year. It is worth noting that this ability to independently project light extinction coefficient adds greatly to model versatility by obviating the necessity to specify the coefficient before using the model. This refinement in model kinetics provides an order of magnitude increase in model reliability and utility over that provided by the original Lake Livingston model.

In Figure P12, generally good agreement is shown between calculated and observed chlorophyll 'a' concentrations in both regions of the reservoir and in both years despite the quite dissimilar data profiles. In 1975 the model reproduces the spring bloom, the summer decline and the fall bloom in the lower reservoir. The upper reservoir segment has only a single bloom occurring after the spring bloom in the lower reservoir. This is also reproduced by the model.

In 1976 the model provides an excellent comparison to the observed data in both the upper and lower reservoir. The shapes of the data profiles differ substantially from those observed in 1975. It is felt that the difference in shape is due mainly to the quite different hydrologies of each year. Flows in 1975 started and remained high until July; flows in 1976 started low, increased to a peak in May, and declined in June. The model correctly calculates the unusual algal bloom shown in the January through March

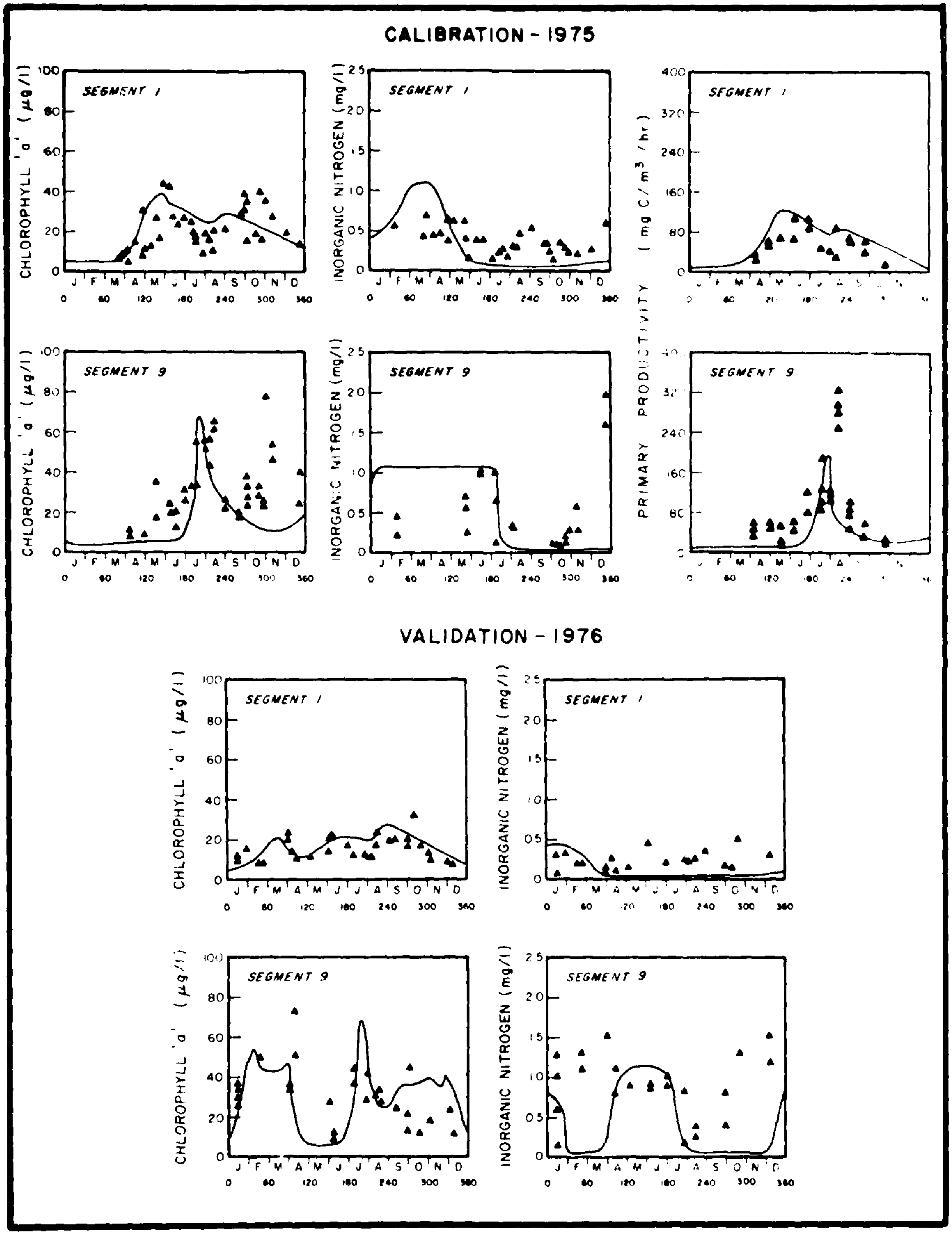


FIGURE P 12

MODEL CALIBRATION AND VALIDATION FOR CHLOROPHYLL 'a', PRIMARY PRODUCTIVITY AND INORGANIC NITROGEN

1976 upper reservoir data as well as the subsequent decline and latter year bloom. Concurrent with the chlorophyll 'a' computations, the model provides an adequate representation of inorganic nitrogen. The discrepancies between model calculated values and the observed data are due mainly to the non-inclusion of known nutrient sources and sinks such as algal nitrogen fixation, nutrient uptake and release by macrophytes, and denitrification in the model kinetics. Thus while the model correctly reproduces the January through the March 1976 bloom in the upper reservoir it does so by the uptake of inorganic nitrogen rather than by nitrogen fixation. The result of this difference is evident in the comparison.

Figure P12 also presents model calculations for primary production, an indication of the rate of carbon fixation in the system. The primary production comparison provides a check on the appropriateness of the chlorophyll 'a' measurement by comparing it to an independent measurement related to biomass and growth rate. Agreement between observed and calculated 1975 primary production values is considered good and is a further indication of the aptness of the chlorophyll 'a' measurement as an indicator of algal population dynamics. No primary production measurements were available for 1976.

Projections

A. Tennessee Colony Lake

The modeling framework calibrated for the Lake Livingston reservoir was utilized for analysis of the eutrophication potential of the proposed Tennessee Colony

Lake. Model constants and coefficients used in the Tennessee Colony model are those determined in the calibration and validation for the Lake Livingston reservoir. Geometry and flow information appropriate to the Tennessee Colony site were used to develop a model specific to the reservoir. In addition, the rating curves developed for the Rosser gage were used to supply boundary conditions for the model. These boundary concentrations, when associated with projected flow conditions, produce the current nutrient and suspended sediment loadings to the lake.

Figure P13 presents the segmentation used for the Tennessee Colony Lake model. Figure P14 presents chlorophyll 'a' concentration projections in the Tennessee Colony Lake for both the low flow year and the high flow year hydrologies. The figure also contains information concerning the sensitivity of the calculations to assumptions of initial conditions in each of the model segments. This is presented as follows: the solid line in each panel presents the model projection for the particular segment for the stated flow condition assuming a relatively high initial nutrient concentration in that segment; the dashed line presents the model projection for that same segment and flow condition for a lower initial nutrient concentration. The cross-hatched areas represent the model sensitivity to initial conditions, and can be considered as a range of chlorophyll 'a' concentrations that might be expected in the lake, subject to antecedent nutrient concentrations. Four segments are shown: segment 1, adjacent to the dam, segment 5, midway in the reservior, adjacent to Richland and Chambers Creeks, segment 9, in the upper reservoir just below Trinidad, and segment 12,

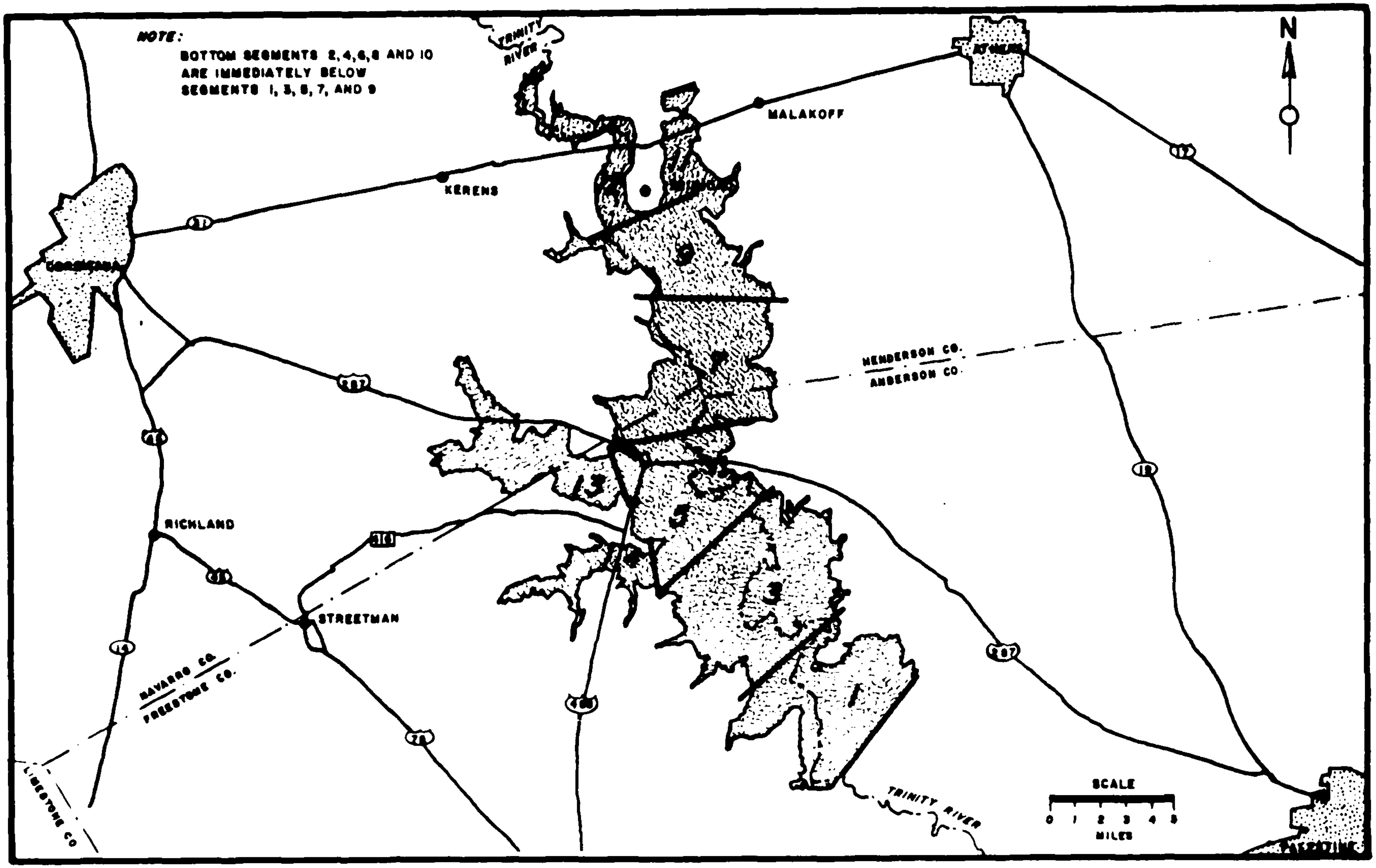


FIGURE P 13
TENNESSEE COLONY LAKE
MODEL SEGMENTATION

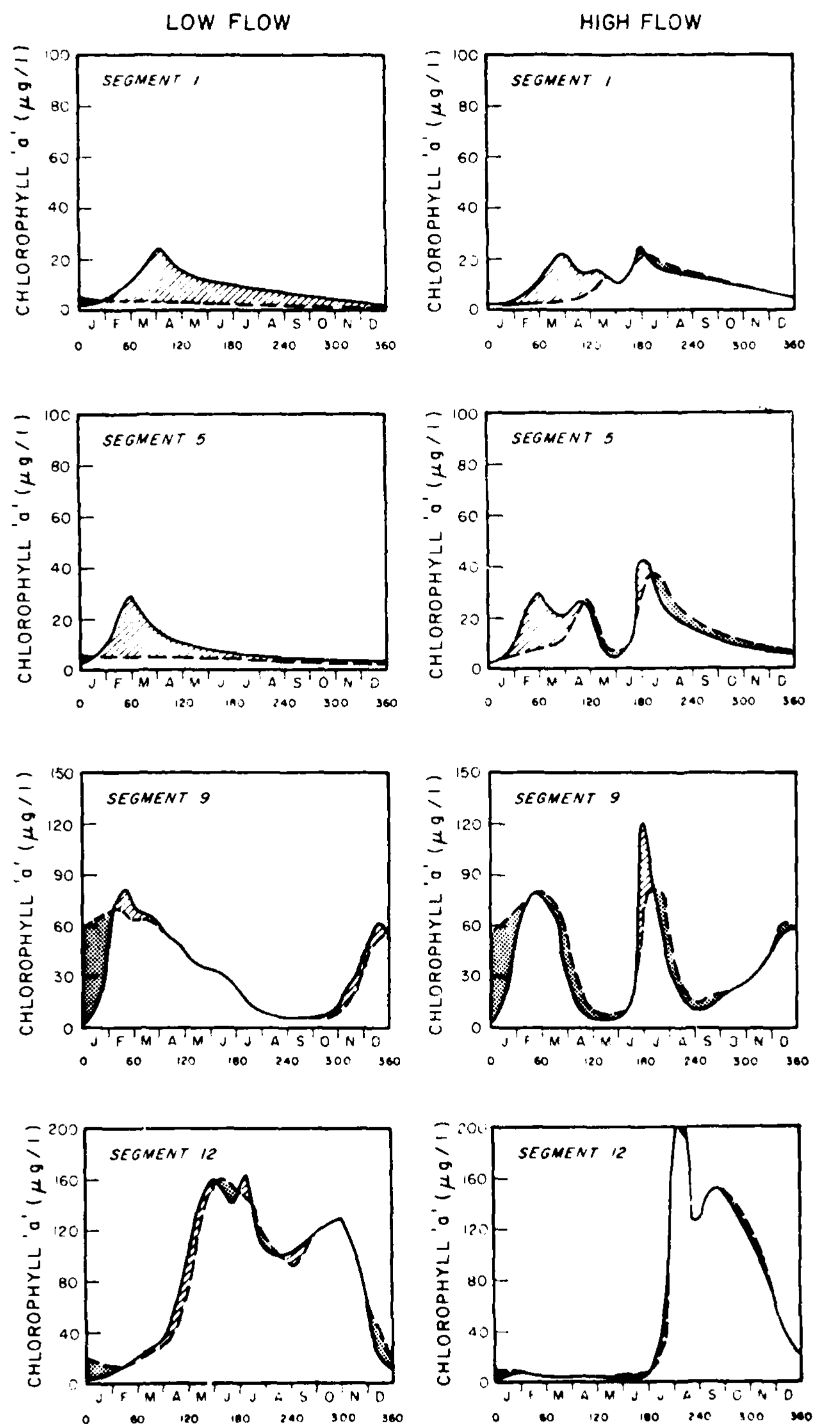


FIGURE P 14

TENNESSEE COLONY LAKE - CHLOROPHYLL 'a' PROJECTIONS adjacent to Trinidad in the mainstem of the Trinity River. Quite different profiles are projected for each location and for each hydrology.

Segment 1, in the lower reservoir is calculated to attain chlorophyll 'a' concentrations between 5 and 20 μg/l with the higher flow maintaining that higher level for a greater portion of the year. This area of the lake is very sensitive to nutrient concentrations existing at the start of the year. Segment 5, midway in the reservoir, is projected to have chlorophyll 'a' levels ranging from 5 to 40 μg/l for the high flow year and from 5 to 20 μg/l for the low flow year. This area is still sensitive to initial nutrient concentrations for both flow conditions. For higher initial concentrations, the reservoir blooms early in both cases. After the early bloom, levels decline and remain low in the low flow year, decrease, but then bloom in the fall in the high flow year. This second bloom in the high flow year is due to the mass of nutrients introduced into the lake during the high flow period.

Segment 9 shows patterns similar to segment 5, but on a magnified scale. Peak chlorophyll 'a' concentrations of 80 μg/l and 120 μg/l are projected for low flow year and high flow year hydrologies, respectively. Little sensitivity to initial conditions remains at this location. Segment 12 is a narrow, relatively shallow portion of the lake, dominated by the advective transport of the Trinity River. Chlorophyll 'a' concentrations of greater than 150 μg/l are projected for both hydrologic situations. Levels in excess of 100 μg/l are projected for more than half the year under low flow conditions, and for approximately four months during the high flow case. This area, because of its short hydraulic detention time, is not sensitive to initial conditions. These projections seem reasonable in light of the fact that, in recent years, chlorophyll 'a' values in the range of 100 to 200 μg/l have been measured during the summer in the section of the Trinity River between Rosser and Crockett.

In 1974 the U.S. Environmental Protection Agency, with the cooperation of the Texas Water Quality Board and the Texas National Guard, conducted sampling programs in each of 39 Texas lakes and reservoirs statewide, as a part of the National Eutrophication Survey. One product of this sampling was a ranking of these 39 Texas water bodies for overall trophic quality. This ranking is based upon a combination of six parameters: median total phosphorus, median inorganic nitrogen, secchi depth, mean chlorophyll 'a', minimum dissolved oxygen, and median dissolved orthophosphorus. The overall ranking is shown in Table P1. The Index Number is the sum of the percent of lakes with higher values for each of the six ranking variables; therefore, a lower index number has been interpreted to indicate a higher trophic level or greater productivity. A similar computation for the proposed Tennessee Colony Lake would result in the reservoir being ranked in the lower 25 percent of the 39 reservoirs listed. This ranking itself does not address the issue of water quality or water use, but does provide an overall comparison among the 39 water bodies sampled. For instance, the Index Number does not present a comparison between any of these lakes and lakes in other states, since the Index Number is a function of

TABLE P1

NES EUTROPHICATION INDICES FOR TEXAS LAKES

Rank	Lake Name	Index Number
1	Canyon Reservoir	445
2	Lake Meredith	441
3	Eagle Mountain Lake	430
4	Kemp Lake	423
5	Amistad Lake	402
6	Brownwood Lake	394
7	Bastrup Lake	393
8	White River Reservoir	390
9	Possum Kingdom Reservoir	387
10	Travis Lake	384
11	Belton Reservoir	384
12	Stillhouse Hollow Reservoir	372
13	Diversion Lake	372
14	Calaveras Lake	362
15	Whitney Lake	357
16	Medina Lake	342
17	Sam Rayburn Reservoir	322
18	E V Spence Reservoir	321
19	Twin Buttes Reservoir	311
20	Lake Colorado City	310
21	Palestine Lake	302
22	Lake of the Pines	298
23	Caddo Lake	297
24	Ft Phantom Hill Lake	296
25	Lake Buchanan	261
26	Stamford Lake	259
27	Lavon Reservoir	258
28	Tawakoni Lake	253
29	Lyndon B. Johnson Lake	238
30	Texoma Lake	217
31	Somerville Lake	208
32	San Angelo Reservoir	200
33	Texarkana Lake	176
34	Garza Little Elm Reservoir	173
35	Trinidad	169
36	Braunig Lake	159
37	Corpus Christi Lake	155
38	Houston Lake	139
39	Livingston Lake	91

the number of lakes included in the ranking. Had a different number of lakes been used in the comparison, the Index Number for each lake above would be different. Further, the Index Number is not interpretable in terms of actual lake trophic state, i.e., it is not possible to state from the Index Number if the lake is eutrophic, mesotrophic or oligotrophic. The Texas Department of Water Resources is currently evaluating the applicability of this ranking system to Texas water bodies and is considering the use of a different approach to assessing lake water quality conditions. It remains for the appropriate regulatory agencies to determine if actual reservoir water quality is representative of either beneficial or deleterious conditions. This judgement depends upon the designated beneficial uses for the water body and the percent impairment of those uses that might result from such water quality.

B. Lake Livingston Reservoir

Projections have also been run for the Lake Livingston reservoir for the low flow and the high flow hydrologies. The solid lines in Figure P15 represent those projections. These chlorophyll 'a' profiles are for present conditions in the reservoir and as such are representative of the range of concentrations that can be expected at the present time. Levels range between 5 and 60 μg/l in low flow years and between 5 and 70 μg/l in high flow years. The patterns themselves shift in response to the flow related nutrient loadings, the flow related extinction coefficient, and the flow related advective transport.

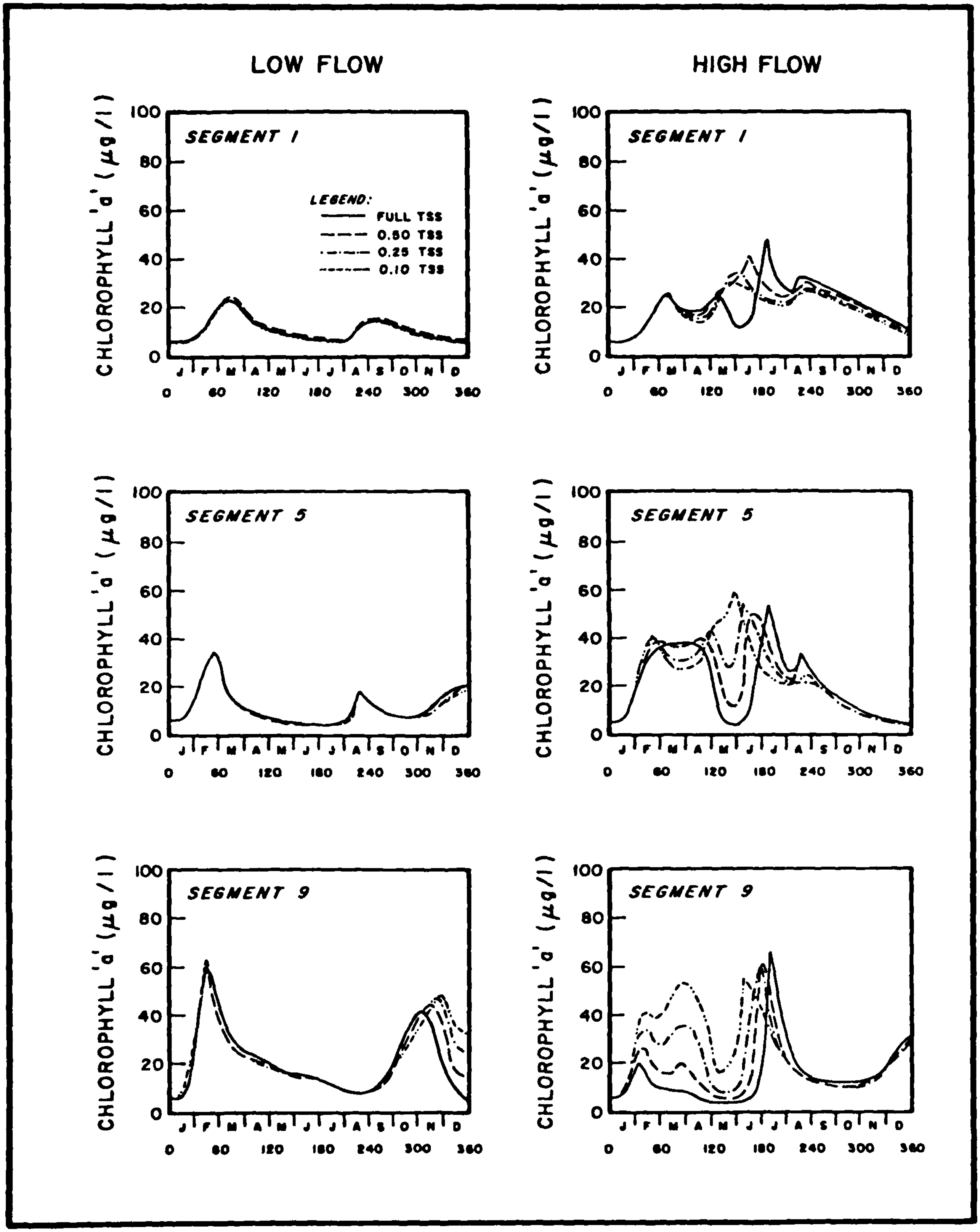


FIGURE P15
LAKE LIVINGSTON RESERVOIR
SENSITIVITY TO SUSPENDED SOLIDS LOADINGS

Impact of Tennessee Colony Lake on Lake Livingston Productivity

Projections have also been made to provide a basis for judging the potential effects that the trapping of suspended solids in Tennessee Colony Lake would have upon Lake Livingston productivity. This was accomplished by reducing the total suspended solids inputs to reducing the total suspended solids inputs to Lake Livingston to one half, one quarter, and one tenth of present levels over the course of the year. These reductions result in changes in lake total suspended solids concentrations, which in turn affect extinction coefficient and carry through to changes in chlorophyll 'a' concentrations. Results are shown on Figure P15. To investigate the effects of changes in suspended sediment loadings only, the model nutrient loadings remain the same for each condition. Under low flow hydrology, projected chlorophyll 'a' levels are unaffected by these reductions in suspended solids. However, some effects are projected for high flow years. These effects include a shifting of the time of occurrence of peak concentrations and a general increase in the average levels of chlorophyll 'a' throughout the year. It is important to note that while these projections indicate a light sensitivity effect in the Lake Livingston reservoir, the reductions in suspended sediment inflow necessary for substantial changes in peak chlorophyll 'a' concentrations are also substantial. Reductions greater than 50 percent in the present high flow year suspended sediment inflow are generally required before changes of more than 5 to 10 μg/l of peak chlorophyll 'a' are projected. However, the effect of the suspended sediment loading on increasing the average level of chlorophyll 'a' throughout a high flow year appears to be more dramatic than the effect on the peak chlorophyll 'a' concentrations alone.

Since the mid-summer, peak concentrations of chlorophyll 'a' were not particularly sensitive to the suspended sediment levels, the conclusion was drawn that these peaks may be more dependent on nutrient concentrations. Previous calculations indicated that chlorophyll 'a' concentrations in the lake were not sensitive to even large reductions in phosphorus loadings since phosphorus levels are greatly in excess of the requirements for algae growth. Thus, it was surmised that the nitrogen loading was the primary influence on the peak chlorophyll 'a' level which would be achieved in the lake at mid-summer periods. Several computer model runs were made to investigate this effect. The resulting trends are illustrated in Figure P16. The upper half of this figure indicates the sensitivity of the peak chlorophyll 'a' concentrations to increases or decreases in nitrogen loads for the current model kinetic structure. It can be seen that the change in peak chlorophyll 'a' concentration in segment 13 is essentially proportional to the nitrogen load. A 50 percent reduction in nitrogen loading to Lake Livingston lowers the mid-summer peak by approximately 50 percent.

The lower portion of Figure P16 presents results based on previous efforts which studied the response of the lake to various nutrient input levels using the original Lake Livingston model (without a suspended solids system and without independent computation of light extinction). These projections are all based on 1975 hydrology. One of these projections was made to

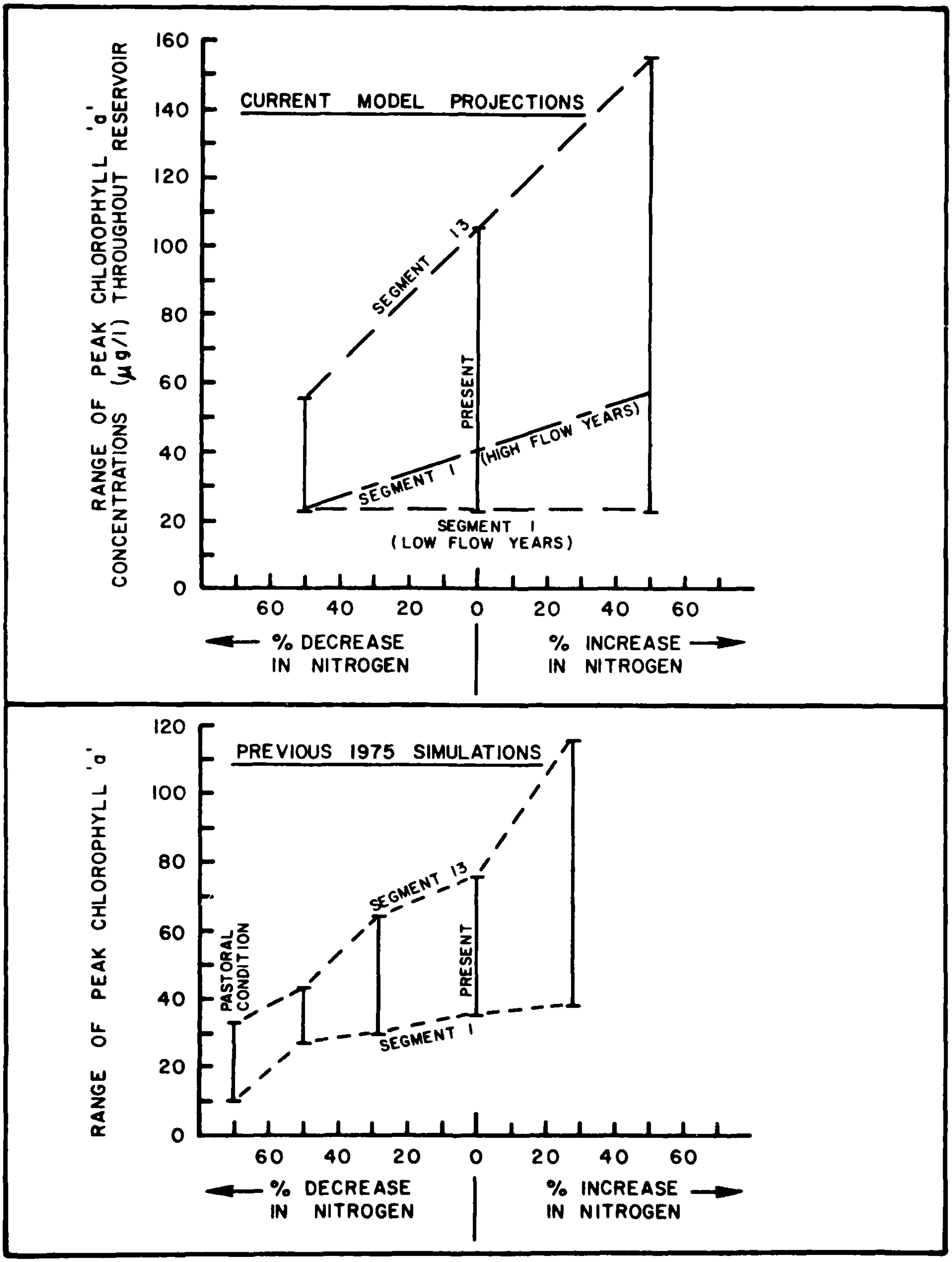


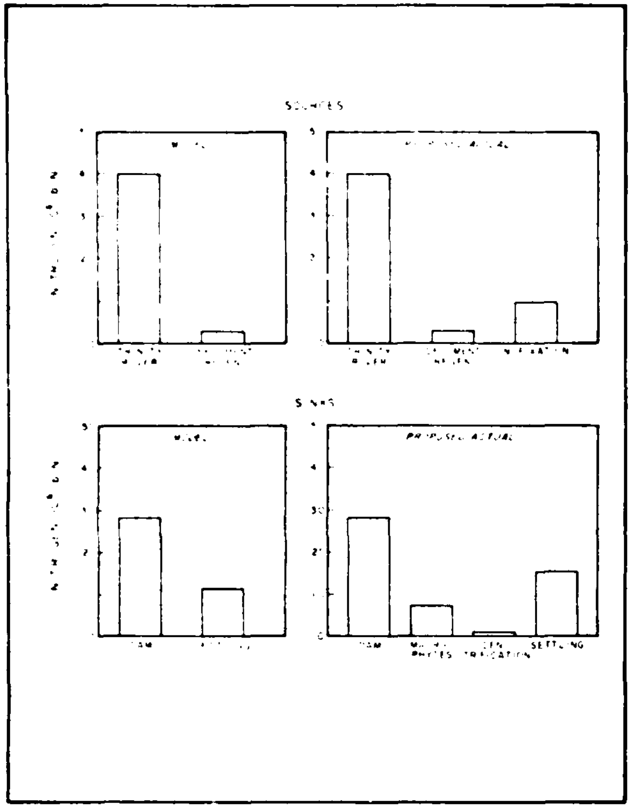
FIGURE P16

EFFECT OF CHANGES IN NITROGEN LOADING ON THE PEAK CHLOROPHYLL 'a' CONCENTRATIONS IN LAKE LIVINGSTON establish the probable baseline conditions for the reservoir. The basic assumption is that all area draining to the reservoir are in either forest or grasslands, and without the man-related influences. This projection has been termed the pastoral baseline and indicates, for 1975 hydrology, an estimate of what would be pre-enrichment state of the reservoir. Reductions of 50 to 60 percent of peak chlorophyll 'a' concentrations could be expected for pastoral nutrient levels as opposed to present nutrient levels. Peak chlorophyll 'a' levels of between 10 to 30 μg/l are projected for the reservoir even under pastoral conditions. The figure also presents a summary of projection results for alternative levels of nitrogen loadings. In each case, the range of peak chlorophyll 'a' calculated anywhere in the reservoir is shown. The sensitivity of the peak chlorophyll 'a' concentrations in segment 13 to nitrogen loading is much the same as the sensitivity shown for the current model projections.

Uncertainties and Problems Remaining

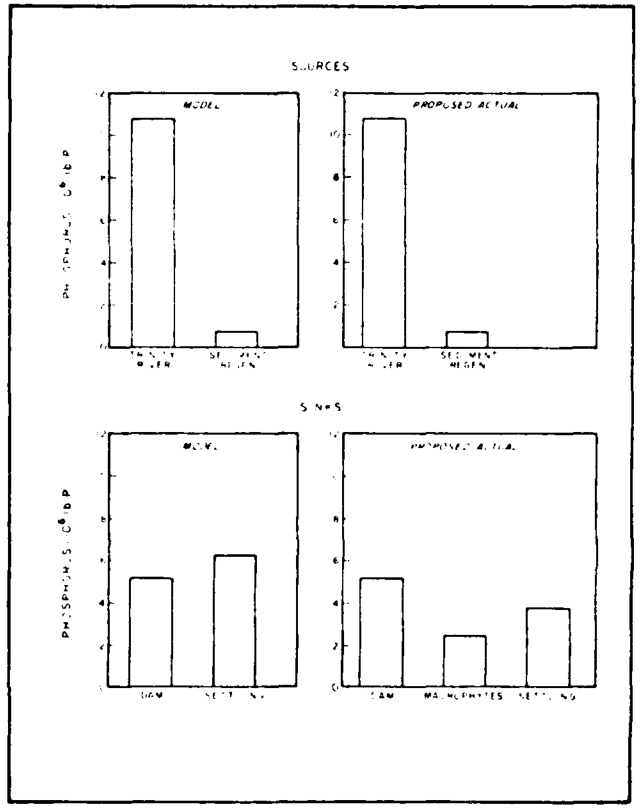
The model developed for Lake Livingston does not directly account for all nutrient sources and sinks identified in the reservoir. Figure P17 presents a comparison of the magnitudes of sources and sinks of nitrogen used in the model with those thought to actually be operative in the prototype. For the model, the Trinity River and sediment nutrient regeneration are nitrogen sources, and dam discharge and settling are sinks. Data

NITROGEN



ACTUAL AND MODEL NITROGEN SOURCES AND SINKS

PHOSPHORUS



ACTUAL AND MODEL PHOSPHORUS SOURCES AND SINKS

FIGURE P17

ACTUAL AND MODEL NUTRIENT SOURCES AND SINKS analysis has identified that nitrogen fixation by algae is an additional source and total macrophytic uptake and denitrification are additional nitrogen sinks. Figure P15 presents a similar comparison for phosphorus, although no fixation source or a process comparable to the denitrification sink exists for phosphorus. The sources and sinks used in the model provide the correct distribution of nutrients, as indicated by comparison to field data, but do so by lumping the individual mechanisms into a net settling term. Depending on the relative magnitudes of actual sources and sinks, the model settling term may over or under estimate settling occurring in the prototype, but overall provides the net nutrient sink of the nutrient observed in the data.

Several conclusions can be drawn from these figures. First, that nitrogen fixation can be a significant source of that nutrient, particularly since fixation occurs at a time of limiting nitrogen levels in the reservoir and is predominantly a phenomenon of blue-green algae, an undesirable species. Second, that substantial portions of the total nutrients entering the reservoir are tied up in macrophyte biomass. Third, that model settling is underestimated for nitrogen and overestimated for phosphorus due to the nitrogen fixation without a similar source for phosphorus.

The exclusion of several prototype sources and sinks casts a degree of uncertainty on the precision of model projections. While the model is capable of reproducing present surface concentrations for each variable of concern, it is not clear that the overall process of settling used to account for the additonal sources and sinks will correctly represent those individual mechanisms under projections conditions.

Additionally, lack of data and the non-inclusion of the aforementioned mechanisms have prevented an adequate validation of the model bottom layer. Taken together these items represent uncertainties which should be considered in evaluating model projections. It is felt however that the trends presented by the projections are indicative of results that might be expected from a given control program.

Auxiliary Studies

A. Trinity River Project Barge Traffic

The development of a multi-purpose channel with lock facilities was an original feature of the Trinity River Project. Two areas of concern related to the multi-purpose channel have been identified and examined within the present study. First, what effect will the channel modifications necessary for barge passage have upon sediment generation, and second, what is the effect of actual barge passage as it pertains to sediment generation and transport. This second effect relates to both propeller scour of bottom materials and bank erosion caused by barge wave wash.

A review of proposed channel modifications relating to barge traffic indicated little effect upon sediment generation. A review of barge traffic literature indicated a scarcity of quantitative information relating to the generation and transport of suspended sediments.

Subsequently, a theoretical model describing barge-channel interactions was postulated. This model has been developed and applied to the Trinity River project situation. The effect of individual barge passage was not addressed. The model considers the impact of barge traffic in terms of a yearly time average effect. On this basis, the order of effects associated with projected barge traffic on suspended sediments is calculated to be small for the study situation. The overall impact of barge traffic and channel modifications related to barge traffic, as compared to other Trinity River sediment sources, is judged to be minimal.

B. Basin Development and Land Use

As a river basin undergoes physical alterations due to basin development, the generation and transport of sediment in and through the basin may change. Such changes will be reflected in changes in actual streamflows and, possibly, changes in the amount of sediment transport per unit of flow.

A methodology for projection of the effect of these changes has been developed. The basis for the analysis is an annual sediment mass balance for the entire river basin based upon sediment rating curves. The basin is described by a number of sub-basins defineable by land use or sediment generation patterns. In this way, changes in a particular sub-basin can be examined for the impact of those changes on any point down river in the basin or on the overall basin itself, for any hydraulic condition. This methodology has been calibrated for the Trinity River Basin and allows for the rational assignment of future sediment loadings due to basin development.

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